

TITLE OF THE INVENTION

SEMICONDUCTOR DEVICE USING FUSE/ANTI-FUSE SYSTEM AND  
METHOD OF MANUFACTURING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

5           This application is based upon and claims the  
benefit of priority from the prior Japanese Patent  
Application No. 2000-039968, filed February 17, 2000,  
the entire contents of which are incorporated herein by  
reference.

10                           BACKGROUND OF THE INVENTION

          The present invention relates to a semiconductor  
device using a fuse/anti-fuse system and a method of  
manufacturing the same.

          In recent years, the semiconductor device is being  
15       made finer and finer to a high degree. In this  
connection, the element isolating region for isolating  
the element is formed mainly by a STI (Shallow Trench  
Isolation) method in place of the conventional LOCOS  
(Local Oxidation Of Silicon) method. It should be  
20       noted, however, that the film formed by the STI method  
has a very high surface flatness, with the result that,  
in the subsequent step of forming the gate electrode,  
it was necessary to employ the stepping process for  
forming an aligning mark.

25           FIGS. 22 to 28 are cross sectional views  
collectively showing the conventional process of  
manufacturing a semiconductor device. The conventional

process of forming a semiconductor device will now be described with reference to FIGS. 22 to 28.

In the first step, a first concave portion 42 providing an element isolation region and a second concave portion 43, which is used in the subsequent lithography process for forming an aligning mark, are formed in a silicon substrate 41 by a lithography technology and an RIE (Reactive Ion Etching) method, as shown in FIG. 28.

In the next step, for example, a silicon oxide film 45 is formed on the entire surface so as to fill the first and second concave portions 42 and 43 with the silicon oxide film 45, as shown in FIG. 29. Then, the silicon oxide film 45 is removed by a CMP (Chemical Mechanical Polish) method until the surface of the silicon substrate 41 is exposed to the outside, thereby forming an element isolating region 46 of an STI structure in the first concave portion 42.

After formation of the element isolating region 46, a resist film 47 is formed on the entire surface, followed by patterning the resist film 47 by the lithography technology and the RIE method, as shown in FIG. 30. Then, the silicon oxide film 45 within the second concave portion 43 is removed by the wet etching performed with the patterned resist film 47 used as a mask, thereby an aligning mark portion 53 is formed in the second concave portion 43. Followed by removing

the resist film 47. In the following description, the step of removing the silicon oxide film 45 buried in the second concave portion 43 is called the stepping process.

5           In the next step, a gate insulating film 48 is formed on the entire surface, as shown in FIG. 31, followed by forming a polycrystalline silicon (polysilicon) film 49 on the gate insulating film 48. Further a tungsten film 50 is formed on the polysilicon  
10 film 49, and a silicon nitride film 51 is formed on the tungsten film 50.

          Then, the silicon nitride film 51, the tungsten film 50, the polysilicon film 49 and the gate  
15 insulating film 48 are selectively removed by the lithography technology and the RIE method, as shown in FIG. 32. As a result, a gate electrode 52 is formed on a predetermined element region 46a. Incidentally, the gate insulating film of the gate electrode 52 is denoted by a reference numeral 48a.

20           In the next step, a gate side wall 55 is formed on the side surface of the gate electrode 52, and source-drain regions 56 are formed in surface regions of the silicon substrate 41 in contact with the edge portions of the gate insulating film 48a by the known  
25 technology, as shown in FIG. 33. Then, an interlayer insulating film 57 is formed on the entire surface, followed by forming a contact plug 58 and an upper

wiring layer 59 and subsequently forming another interlayer insulating film 60 on the entire surface.

Where the tungsten film 50, etc. is used as a part of the gate electrode 52 as described above, it is difficult to read the difference in the film quality of the underlying layer by an optical method because the tungsten film 50 has a high reflectance. Therefore, if the stepping process for forming the aligning mark portion 53, which is shown in FIG. 30, is omitted, it is impossible to read the aligning mark portion 53 by an optical method in the case of employing because the aligning mark portion 53 is no step, for example, the STI method that permits the formed film to have a high degree of surface flatness. It follows that the problem of the deviation in the alignment between the element isolating region 46 (or element region 46a) and the gate electrode 52 is rendered serious.

As described above, the lithography step and the etching step included in the stepping process are indispensable for avoiding the problem of the deviation in the alignment. However, since these steps are used solely for the stepping of the aligning mark portion 53, it was desirable to omit these steps or to effectively utilize these steps.

On the other hand, in, for example, a DRAM (Dynamic Random Access Memory), the apparatus is equipped in many cases with a remedy circuit for

substituting an auxiliary cell for the defective cell  
in order to improve the yield of the product. For the  
judgment of the cell that is to be renewed, it was  
customary to use a fuse of the type that the wiring  
5 made of mainly aluminum is fused away by a laser beam.  
On the other hand, proposed is an anti-fuse in which  
the judgment is performed by breaking the gate  
insulating film in a predetermined portion.

The anti-fuse is expected to produce various  
10 merits. For example, the anti-fuse is expected to  
decrease the occupies area within the chip and to  
permit replacing the final defective cell after the  
package sealing. Also, in the anti-fuse, a desired  
gate insulating film is broken to make the device  
15 conductive by applying a voltage higher than the  
breakdown voltage. Therefore, in general, the anti-  
fuse is connected to a high voltage generating circuit  
for breaking the gate insulating film and to a judging  
circuit for detecting whether the anti-fuse portion is  
20 broken or not. It follows that, in breaking the anti-  
fuse portion, the gate insulating film in the judging  
circuit portion also receives a damage to some extent.  
Such being the situation, it was desirable to permit  
the anti-fuse portion to be broken with a reasonably  
25 low voltage while suppressing the damage done to the  
judging circuit and other portions as much as possible.

Also, in order to suppress the increase in

the number of manufacturing steps, it is desirable to form the gate insulating film in the anti-fuse portion simultaneously with formation of the gate insulating film of the MOS transistor. However, it was difficult to form the gate insulating film of the anti-fuse portion having a low breakdown voltage simultaneously with formation of the gate insulating film included in the ordinary transistor and having a high reliability. Under the circumstances, it was difficult to put to the practical use the anti-fuse utilizing the gate insulating film formed for the transistor.

#### BRIEF SUMMARY OF THE INVENTION

An object of the present invention, which has been achieved in an attempt to solve the above-noted problems, is to provide a semiconductor device that permits forming a gate insulating film having a desired breakdown voltage without increasing the number of manufacturing steps by applying the stepping process for forming an aligning mark to the formation of the anti-fuse and a method of manufacturing the particular semiconductor device.

According to a first aspect of the present invention, which permits achieving the object described above, there is provided a semiconductor device, comprising a concave portion formed in a semiconductor substrate, a first gate insulating film formed selectively on the semiconductor substrate, a second

gate insulating film formed in at least the bottom surface of the concave portion, a first conductive film formed on the first gate insulating film, and a second conductive film formed on the second gate insulating film.

It is possible for the second gate insulating film and the second conductive film to be formed on the bottom surface of the concave portion, on at least one side surface of the concave portion and on the semiconductor substrate. It is also possible for the surface of the first conductive film to be flush with the surface of the second conductive film formed on the semiconductor substrate.

It is possible for the second gate insulating film to be formed in the corner portion of the concave portion.

It is also possible for an insulating film to be formed on the second conductive film and for the concave portion to be filled with the insulating film, the second gate insulating film and the second conductive film. Further, it is possible for the concave portion to be filled with the second gate insulating film and the second conductive film and for the surface of the second conductive film to be substantially flat.

It is possible for the semiconductor substrate to be an SOI substrate.

It is possible for the semiconductor device to further comprise an element isolating region formed within the semiconductor substrate such that the second gate insulating film and the second conductive film are allowed to extend over the element isolating region, a contact electrically connected to that portion of the second conductive film which is positioned on the element isolating region, and a wiring electrically connected to the contact.

It is possible for a plurality of concave portions to be formed in the semiconductor substrate such that these concave portions are filled with the second gate insulating film and the second conductive film and for the surface of the second conductive film to be substantially flat.

It is possible for a plurality of gate electrodes each consisting of the second conductive film to be formed in the concave portions.

It is possible for the impurity concentration in the second conductive film to be higher than that in the semiconductor substrate.

The second insulating film functions as the insulating film for the anti-fuse portion or for the capacitor element.

According to a second aspect of the present invention, there is provided a method of manufacturing a semiconductor device, comprising the steps of forming



first, second and third concave portions in a semiconductor substrate; burying an insulating film in the first, second and third concave portions, followed by planarizing the surface of the insulating film  
5 until the surface of the semiconductor substrate is exposed to the outside so as to form an element isolating region within the first concave portion; removing the insulating film from the second and third concave portions so as to form a aligning mark  
10 portion in the second concave portion; forming a gate insulating film on the entire surface; forming a conductive film on the gate insulating film; and selectively removing the conductive film so as to form a first gate electrode on the semiconductor substrate,  
15 and to form a second gate electrode in the third concave portion.

It is possible to form a gate insulating film on the entire surface, with the insulating film formed within the third concave portion partly left unremoved.

20 It is possible to form the second gate electrode on the bottom surface of the third concave portion, on the both side surfaces or one side surface of the third concave portion, and on the semiconductor substrate.

It is possible to form the second gate electrode  
25 in a manner to fill the third concave portion.

It is possible to form the second gate electrode in a manner to extend from within the third concave

portion onto the element isolating region and to form the contact on that portion of the second gate electrode which is positioned on the element isolating region.

5           It is possible to form a plurality of third concave portions. It is also possible to form a plurality of second gate electrodes within the third concave portions.

10           It is possible for the impurity concentration of the conductive film to be higher than that of the semiconductor substrate.

          The second gate electrode functions as the gate electrode for the anti-fuse portion or for the capacitor element.

15           As described above, the present invention provides a semiconductor device that permits forming a gate insulating film having a desired breakdown voltage without increasing the number of manufacturing steps by applying the stepping process for the aligning mark to  
20           the anti-fuse formation and a method of manufacturing the particular semiconductor device.

          Additional objects and advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may  
25           be learned by practice of the invention. The objects and advantages of the invention may be realized and obtained by means of the instrumentalities and

combinations particularly pointed out hereinafter.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate presently preferred embodiments of the invention, and together with the general description given above and the detailed description of the preferred embodiments given below, serve to explain the principles of the invention.

FIG. 1 is a cross sectional view showing a step of manufacturing a semiconductor device according to a first embodiment of the present invention;

FIG. 2 is a cross sectional view showing the step following the step shown in FIG. 1 of manufacturing a semiconductor device according to a first embodiment of the present invention;

FIG. 3 is a cross sectional view showing the step following the step shown in FIG. 2 of manufacturing a semiconductor device according to a first embodiment of the present invention;

FIG. 4 is a cross sectional view showing the step following the step shown in FIG. 3 of manufacturing a semiconductor device according to a first embodiment of the present invention;

FIG. 5 is a cross sectional view showing the step following the step shown in FIG. 4 of manufacturing a semiconductor device according to a first embodiment

of the present invention;

FIG. 6 is a cross sectional view showing the step following the step shown in FIG. 5 of manufacturing a semiconductor device according to a first embodiment of the present invention;

FIG. 7 is a cross sectional view showing a manufacturing process of a semiconductor device according to a modification of the first embodiment of the present invention;

FIG. 8 is a cross sectional view relating to a second embodiment of the present invention and showing an anti-fuse portion utilizing a corner portion of a concave portion;

FIG. 9 is a cross sectional view relating to the second embodiment of the present invention and showing another anti-fuse portion utilizing a corner portion of a concave portion;

FIG. 10 is a cross sectional view relating to the second embodiment of the present invention and showing an anti-fuse portion utilizing a corner portion on one side of a concave portion;

FIG. 11 is a cross sectional view relating to the second embodiment of the present invention and showing an anti-fuse portion in the case of filling the concave portion;

FIG. 12 is a cross sectional view relating to the second embodiment of the present invention and showing

an anti-fuse portion in the case of filling the concave portion with a polysilicon film;

FIG. 13 is a cross sectional view relating to the first and second embodiments of the present invention and showing an anti-fuse portion in the case of using an SOI substrate;

FIG. 14 is a cross sectional view relating to the first and second embodiments of the present invention and showing an anti-fuse portion in the case where the concave portion is partly filled with a silicon oxide film;

FIG. 15 is a cross sectional view relating to the first and second embodiments of the present invention and showing an anti-fuse portion in the case of forming a contact on the element isolating region;

FIG. 16 is a cross sectional view relating to the first and second embodiments of the present invention and showing the case where a plurality of concave portions correspond to a single anti-fuse portion;

FIG. 17 is a cross sectional view relating to the first and second embodiments of the present invention and showing the case where a single concave portion corresponds to a plurality of anti-fuse portions;

FIG. 18 is a cross sectional view relating to a third embodiment of the present invention and showing an anti-fuse portion in which the impurity concentration in the gate is higher than that in

the well;

FIG. 19 is a cross sectional view relating to the third embodiment of the present invention and showing an anti-fuse portion in which the impurity concentration in the gate is higher than that in the well, and an LDD region is formed;

FIG. 20 is a cross sectional view relating to the third embodiment of the present invention and showing an anti-fuse portion in which the impurity concentration in the gate is higher than that in the well;

FIG. 21 is a cross sectional view relating to the third embodiment of the present invention and showing an anti-fuse portion in which the impurity concentration in the gate is higher than that in the well;

FIG. 22A is an plan view showing the case where a gate electrode for a plurality of anti-fuses is formed in a single concave portion;

FIG. 22B is a cross sectional view along the line 22B-22B shown in FIG. 22A;

FIG. 23A is an plan view showing the case where a concave portion is filled with a gate electrode for an anti-fuse and a contact is formed on an element isolating region;

FIG. 23B is a cross sectional view along the line 23B-23B shown in FIG. 23A;

FIG. 24A is a plan view showing the case where the corner portion of a concave portion is positively utilized;

FIG. 24B is a cross sectional view along the line  
5 24B-24B shown in FIG. 24A;

FIG. 25A is a plan view showing the case where an acute angle portion is formed in a concave portion;

FIG. 25B is a cross sectional view along the  
line 25B-25B shown in FIG. 25A;

FIG. 26 is a cross sectional view showing a  
10 semiconductor device having a capacitor element and prepared by a conventional technology;

FIG. 27A is a cross sectional view relating to  
a fifth embodiment of the present invention and showing  
15 a semiconductor device having a capacitor element;

FIG. 27B is a plan view showing the concave  
portion shown in FIG. 27A;

FIG. 28 is a cross sectional view showing a  
manufacturing step of a conventional semiconductor  
20 device;

FIG. 29 is a cross sectional view showing the step  
following the step shown in FIG. 28 of manufacturing  
the conventional semiconductor device;

FIG. 30 is a cross sectional view showing the step  
25 following the step shown in FIG. 29 of manufacturing  
the conventional semiconductor device;

FIG. 31 is a cross sectional view showing the step

following the step shown in FIG. 30 of manufacturing the conventional semiconductor device;

FIG. 32 is a cross sectional view showing the step following the step shown in FIG. 31 of manufacturing the conventional semiconductor device; and

FIG. 33 is a cross sectional view showing the step following the step shown in FIG. 32 of manufacturing the conventional semiconductor device.

#### DETAILED DESCRIPTION OF THE INVENTION

Preferred embodiments of the present invention will now be described with reference to the accompanying drawings. Throughout the drawings, the common portions are denoted by common reference numerals.

#### [First Embodiment]

The method of manufacturing a semiconductor device according to a first embodiment of the present invention is featured in that a concave portion for an anti-fuse portion is formed simultaneously with formation of a concave portion (stepped portion) for an aligning mark portion. As a result, it is possible to effectively utilize the lithography step and the etching step in the formation of a concave portion for an aligning mark portion.

FIGS. 1 to 6 are cross sectional views collectively showing a method of manufacturing a semiconductor device according to the first embodiment



of the present invention. The manufacturing method of a semiconductor device according to the first embodiment of the present invention will now be described with reference to these drawings.

5           In the first step, a first concave portion 12 forming an element isolating region is formed in a silicon substrate 11 by a lithography technology and a RIE (Reactive Ion Etching) method, as shown in FIG. 1. In this step, a second concave portion 13  
10           forming an aligning mark portion, which is utilized in the subsequent lithography step, and a concave portion 14 for an anti-fuse portion are formed in the silicon substrate 11 simultaneously with formation of the first concave portion 12.

15           Then, a silicon oxide film 15 is formed on the entire surface so as to fill the first, second and third concave portions 12, 13 and 14, as shown in FIG. 2, followed by removing the silicon oxide film 15 by a CMP (Chemical Mechanical Polish) method until the  
20           surface of the silicon substrate 11 is exposed to the outside. As a result, an element isolating region 16 of an STI structure is formed in the first concave portion 12.

          In the next step, a resist film 17 is formed on  
25           the entire surface, followed by patterning the resist film 17, as shown in FIG. 3. Then, the silicon oxide film 15 within the second concave portion 13 and the

third concave portion 14 is removed by a wet etching performed by using the patterned resist film 17 as a mask, thereby an aligning mark portion 23 is formed in the second concave portion 13. Then, the patterned resist film 17 is removed.

Then, a gate insulating film 18 is formed on the entire surface as shown in FIG. 4, followed by forming a polysilicon film 19 on the gate insulating film 18. The gate insulating film 18 is formed of any of, for example, a silicon oxide film, a silicon nitride film and a silicon oxynitride film. After formation of the polysilicon film 19, a tungsten film 20 is formed on the polysilicon film 19, followed by forming a silicon nitride film 21 on the tungsten film 20.

After formation of the silicon nitride film 21, the silicon nitride film 21, the tungsten film 20, the polysilicon film 19 and the gate insulating film 18 are selectively removed by the lithography technology and the RIE method, as shown in FIG. 5. As a result, a first gate electrode 22 is formed on a predetermined element region 16a. At the same time, a second gate electrode 24 for an anti-fuse portion is formed in a bottom surface of the third concave portion 14. Incidentally, the gate insulating film for the first gate electrode 22 is denoted by a reference numeral 18a. Likewise, the gate insulating film for the second gate electrode 24 is denoted by a reference

numeral 18b. It is possible for the gate insulating film 18 not to be removed so as to remain on the entire substrate surface.

5 In the next step, a gate side wall 25 is formed  
on the side surfaces of the first and second gate  
electrodes 22 and 24, etc. by the known technology, as  
shown in FIG. 6, followed by forming source-drain  
regions 26 in surface regions of the silicon substrate  
11 on both sides of the first gate electrode 22. Then,  
10 an interlayer insulating film 27 is formed on the  
entire surface, followed by forming a contact plug 28  
and an upper wiring layer 29 for electrically  
connecting the second gate electrode 24 to another  
element. Finally, another interlayer insulating film  
15 30 is formed on the entire surface.

According to the first embodiment of the present  
invention described above, the gate insulating film 18  
for the anti-fuse is formed on a bottom surface of the  
third concave portion 14. It should be noted that  
20 a damage is done to the bottom surface of the third  
concave portion 14 by the RIE process employed for  
forming the concave portions 12, 13 and 14. Therefore,  
it is possible to lower the breakdown voltage of the  
gate insulating film 18b formed in the concave portion  
25 14, compared with the gate insulating film 18a of the  
transistor formed on the surface of the substrate 11.  
It follows that it is possible to break only the gate

insulating film 18b for the anti-fuse without applying an extremely high voltage. This makes it possible to suppress the damage done to the gate insulating film 18a of the transistor included in, for example, a judging circuit portion. It follows that it is possible to maintain a high reliability of the transistor and to improve the yield.

It should also be noted that the concave portion 14 for the anti-fuse portion is also formed in the lithography and etching steps for forming the concave portion 13 for the aligning mark portion 23, and the gate insulating film 18a for the transistor is formed simultaneously with formation of the gate insulating film 18b for the anti-fuse portion. As a result, it is unnecessary to employ additional manufacturing steps for forming the anti-fuse portion. It follows that the manufacturing cost of the semiconductor device can be lowered.

In the first embodiment, the lower end portion of the resist film 17 for forming the third concave portion 14 for the anti-fuse, which is shown in FIG. 3, is positioned outside the upper edge portion of the third concave portion 14. Therefore, the silicon oxide film 15 within the third concave portion 14 is removed completely in the etching step. However, the positional relationship between the third concave portion 14 and the lower end portion of the resist

film 17 is not limited to that shown in the drawing.

For example, where the lower end portion of the resist film 17 is positioned inside the upper edge portion of the third concave portion 14, it is possible to permit the silicon oxide film 15 to remain partly within the third concave portion 14, as shown in FIG. 7. It should be noted that, in the step of forming the gate electrode, a damage is done to the gate insulating film in the edge portion of the gate electrode in the step of, for example, the RIE process, making it impossible to adjust completely the nonuniformity in the breakdown voltage of the gate electrode. However, in the structure shown in FIG. 7, the remaining silicon oxide film 15 resides in the edge portion of the gate electrode 24. It follows that the breakdown at the edge portion of the gate electrode 24 can be suppressed by the insulating film formed of the silicon oxide film 15, making it possible to adjust the nonuniformity in the breakdown voltage of the gate insulating film 18b.

[Second Embodiment]

In the second embodiment, the shape of the gate electrode for the anti-fuse is modified in order to positively utilize the corner portion of the concave portion for the anti-fuse. Incidentally, the manufacturing method according to the second embodiment is substantially equal to that according

to the first embodiment and, thus, the following description covers only the structure differing from that in the first embodiment.

As shown in FIG. 8, the gate electrode 24 is  
5 formed on the bottom surface and the side surface of the concave portion 14 and on the semiconductor substrate 11 for covering corner portions 14a, 14b of the concave portion 14 for the anti-fuse.

Where a plurality of concave portions 14 are  
10 formed as shown in FIG. 9, the gate electrode 24 is formed on the bottom surfaces and side surfaces of the concave portions 14 and on the semiconductor substrate 11 in a manner to cover the plural concave portions 14 for covering the corner portions 14a, 14b  
15 of the concave portion 14 for the anti-fuse.

According to the second embodiment, the corner portions 14a and 14b of the concave portion 14 are used as anti-fuse. Therefore, the electric field concentration occurs on particularly the corner  
20 portions 14a and 14b so as to make it possible to break effectively the gate insulating film 18b.

Also, it is possible to form the gate electrode 24 on the corner portions 14a, 14b on only one side of the concave portion 14, as shown in FIG. 10. In this case,  
25 it is possible to obtain the effect of diminishing the area occupied by the anti-fuse in addition to the effects described above.

Also, where the gate insulating film 18b is formed by, for example, oxidation in place of the deposition, the gate insulating film (oxide film) 18b can be made thinner in the corner portions 14a, 14b than in the other flat portion, making it possible to lower specifically the breakdown voltage in only the corner portions 14a, 14b.

As described above, according to the second embodiment, the breakdown voltage can be made lower than in the first embodiment in only the anti-fuse portion of the specified portion (corner portions 14a, 14b). As a result, the damage done to the other transistors can be further suppressed so as to improve the reliability of the semiconductor device and the yield.

Incidentally, in the second embodiment of the present invention, it is possible to form the concave portion 14 having a width smaller than that of the concave portion 14 shown in FIGS. 8 and 9 and to fill the concave portion 14 with a gate electrode material (polysilicon film 19), as shown in FIGS. 11 and 12. Where the polysilicon film 19 is thin as shown in FIG. 11, the concave portion 14 is not filled completely with the polysilicon film 19, giving rise to formation of a concavity in the central portion of the polysilicon film 19. In this case, the concavity of the polysilicon film 19 is filled with an insulating

film (silicon nitride film 21) providing the cap film of the gate electrode. Also, where the polysilicon film 19 has a sufficiently large thickness, the concave portion 14 is filled completely with the polysilicon film 19, as shown in FIG. 12. Therefore, the silicon nitride film 21 covers the tungsten film 20 formed on the outside of the concave portion 14.

It should be noted that the polysilicon film 19 and the silicon nitride film 21 are formed in many cases by, for example, an LPCVD (Low Pressure Chemical Vapor Deposition) method that is carried out under high temperatures, e.g., several hundred °C. Therefore, stress derived from the difference in the thermal expansion coefficient is generated under room temperature under which the semiconductor device is actually used. It follows that the breakdown voltage of the anti-fuse portion can be further lowered, compared with the semiconductor device shown in, for example, FIGS. 8 and 9. It should also be noted that, since the gate electrode 24 extends onto the silicon substrate 11, the gate electrodes 22 and 24 for the transistor and the anti-fuse can be formed in the same height in the lithography step for forming the gate electrodes 22 and 24. This facilitates the lithography step and further improves the yield. Incidentally, the structure shown in FIG. 12 produces the effect that a position alignment between the



contact plug 28 and the tungsten film 20 is easy,  
compared with the structure shown in FIG. 11.

In each of the first and second embodiments of  
the present invention described above, the silicon  
5 substrate 11 is used as the semiconductor substrate.  
However, the semiconductor substrate used in the  
present invention is not limited to the silicon  
substrate 11. For example, it is also possible to use  
as the semiconductor substrate an SOI (Silicon On  
10 Insulator) substrate 31 consisting of an insulating  
layer 31a and a silicon layer 31b, as shown in FIG. 13.

In each of the first and second embodiments of the  
present invention described above, the silicon oxide  
film 15 within the concave portion 14 is removed  
15 completely in the stepping process shown in FIG. 3.  
However, it is not absolutely necessary in the present  
invention to remove completely the silicon oxide film  
15 within the concave portion 14. For example, it is  
also possible to leave the silicon oxide film 15  
20 unremoved in a part of the concave portion 14, as shown  
in FIG. 14. In this case, even if a damage is done to  
the bottom surface of the concave portion 14 in the RIE  
step for forming the concave portion 14, it is possible  
to suppress the nonuniformity in the breakdown voltage  
25 of the gate insulating film by forming the silicon  
oxide film 15 on the bottom surface of the concave  
portion 14 after formation of the concave portion 14.

Incidentally, where the width of the concave portion 14 is relatively large and the gate electrode 24 is formed on the bottom surface and side surface of the concave portion 14 and on the silicon substrate 11 as shown in FIGS. 13 and 14, a stepped portion 24' of the gate electrode 24 is formed in the center of the concave portion 14. Therefore, the area occupies by the element can be further diminished, if the stepped portion 24' is utilized as an aligning mark portion.

Also, as shown in FIG. 15, it is possible to form the contact plug 28 for the electrical connection to the gate electrode (not shown) of another element above the element isolating region 16. Where a contact hole is formed on an element region, a damage is done to the gate insulating film right under the contact hole in the RIE step for forming the contact hole, giving rise to a possibility of generating a nonuniformity in the breakdown voltage. In the case of the structure shown in FIG. 15, however, it is possible to suppress the nonuniformity in the breakdown voltage derived from the damage generated in the step of forming the contact hole because the contact hole is formed above the element isolating region.

In each of the first and second embodiments of the present invention described above, the gate electrode 24 for the anti-fuse and the concave portion 14 correspond to each other in a 1:1 relationship.

However, the present invention is not limited to these  
embodiments. For example, it is possible to form  
a plurality of concave portions 14 in a manner to  
correspond to a single gate electrode 24, as shown in  
5 FIG. 16. In this case, the breakdown voltage is  
stabilized, and the yield of the anti-fuse is improved.  
It is also possible to form a plurality of gate  
electrodes 24 within a single concave portion 14, as  
shown in FIG. 17. In this case, the area occupied by  
10 the anti-fuse portion can be further diminished.

[Third Embodiment]

In forming a transistor, e.g., when it comes to  
a CMOS (Complementary MOS) device using a polysilicon  
gate, an N-type or P-type ion implantation is performed  
15 in the steps for forming the well, the channel region,  
the gate electrode, the source-drain regions and  
the LDD (Lightly Doped Drain) region. In the third  
embodiment, the breakdown voltage of the gate  
insulating film in the anti-fuse portion is adjusted by  
20 utilizing these steps in combination. The method of  
adjusting the breakdown voltage of the gate insulating  
film in the anti-fuse portion and the method of  
decreasing the resistance of the conductive portion  
after the breakdown will now be described in the  
25 following.

As shown in FIG. 18, the conductivity type, e.g.,  
P-type, of a well 32a formed in a surface region of

the silicon substrate 11 is made equal to that of a polysilicon film 19a. As a result, it is possible to lower the resistance of the anti-fuse portion after breakdown of the gate insulating film 18b

5 so as to improve the accuracy of judgement of breakdown/non-breakdown.

As shown in FIG. 19, the conductivity type, e.g., N-type, of the well 32 formed in a surface region of the silicon substrate 11 is made equal to that of the polysilicon film 19b. Further, a P-type LDD region and source-drain regions 33 are formed in surface regions of the N-well 32b. For breaking down the gate insulating film 18b, a positive electric field is applied to the gate electrode 24. In this case, the electric field concentration on the edge portions 24a of the gate electrode 24 can be moderated by the formation of the LDD region and the source-drain regions 33. It follows that it is possible to suppress the nonuniformity in the breakdown voltage derived from the electric field concentration on the gate electrode edge portions 24a.

Also, as shown in FIG. 20, the conductivity, e.g., N-type, of the well 32b formed in a surface region of the silicon substrate 11 is made equal to that of the polysilicon film 19b, and the impurity concentration in the polysilicon film 19b is made higher by at least one place than that in the well 32b. Incidentally, in this

apparatus, a positive electric field is imparted to the gate electrode 24 in breaking down the gate insulating film 18b in the anti-fuse portion, and a negative electric field is imparted to the gate electrode 24

5 when the apparatus is actually used for performing the judgement. Where the polarities of the electric field in the breakdown step and the judging step are made opposite to each other, the depletion layer formed in the well 32b on the lower side of the gate is thickened  
10 in the judging step because the impurity concentration in the well 32b is lower than that in the polysilicon film 19b. As a result, only an effectively low electric field is applied to the gate insulating film in the anti-fuse portion that was not broken down.

15 It follows that it is possible to increase the reliability of the judging operation that is repeatedly performed in actually using the apparatus.

Also, in each of the embodiments described above, it is possible to implant a channel impurity into  
20 a region right under the gate electrode 24 in the anti-fuse portion in accordance with formation of a transistor. Alternatively, it is also possible to keep, for example, the P-type semiconductor substrate 34 under the state of a low impurity concentration as  
25 shown in FIG. 21 without applying an ion implantation to the well and the channel region of the anti-fuse portion. Where the gate insulating film 18b in

the anti-fuse portion is broken down in this apparatus,  
a negative electric field is imparted to the gate  
electrode 24, and a positive electric field is imparted  
to the gate electrode 24 in performing the judging  
5 operation. The effect similar to that obtained in the  
structure shown in FIG. 20 can be obtained in this  
case, too. Further, since the original impurity  
concentration in the semiconductor substrate 34 itself  
is very low, the thickness of the depletion layer can  
10 be further increased so as to further improve the  
reliability of the judging operation in actually using  
the apparatus.

The method of adjusting the breakdown voltage of  
the gate insulating film 18b in the anti-fuse portion  
15 is not limited to that described in the embodiment  
described above.

For example, it is possible to adjust the  
breakdown voltage of the anti-fuse by adjusting  
the amount of damage done to the bottom portion, the  
20 side surface and the corner portions of the concave  
portion 14. To be more specific, where the breakdown  
voltage is rendered lower than a predetermined value,  
and where the decrease of the breakdown voltage is  
derived from the damage caused by the RIE treatment,  
25 it is possible to decrease the amount of the damage  
by decreasing the ion energy in the RIE step. As a  
result, the breakdown voltage can be restored to

some extent.

Also, the damaged layer in the uppermost surface of the silicon substrate 11 can be removed by etching thin the surface of the silicon substrate 11 by an isotropic etching such as a CDE (Chemical Dry Etching) method in removing the silicon oxide film 15 in the stepping process shown in FIG. 3. It is also possible to weaken the effect of the electric field concentration by making roundish the corner portions 14a and 14b of the concave portion 14. The breakdown voltage rendered lower than a predetermined value can be restored to some extent by these methods, too.

By contraries, where it is desired to further lower the breakdown voltage, it is possible to further introduce damages to the bottom surface of the concave portion 14 by using a RIE method having a high power in place of the wet etching method in removing the silicon oxide film 15 in the stepping process.

Further, after removal of the silicon oxide film 15 in the stepping process, an impurity ion is introduced by using the ion implantation technology before the resist film 17 is peeled off. As a result, it is possible to control the thickness of the gate oxide film 18 formed in the subsequent process. It follows that it is possible to control the breakdown voltage of the gate insulating film 18b. For example, after the lithography process for the stepping, an

nitrogen ion implantation is performed. Thereby it is possible to form the thin thickness of the gate oxide film 18 formed in the subsequent process, it is possible to gain the breakdown voltage of the predetermined value by the film 18 is used as anti-fuse. In this case, the stepped portion of the anti-fuse portion is not always necessary, however it is possible to low the breakdown voltage by the stepped portion.

[Fourth Embodiment]

The fourth embodiment is directed to the plan views of the semiconductor devices according to the first to third embodiments of the present invention. Incidentally, a reference numeral 14c shown in each of FIGS. 22A to 25A denotes a mask.

FIG. 22A is a plan view covering the case where a plurality of gate electrodes 24 for the anti-fuse are formed in a single concave portion 14 as shown in FIG. 17. FIG. 22B is a cross sectional view along the line 22B-22B shown in FIG. 22A. In this case, the gate electrodes 24 are formed in the form of islands within the concave portion 14.

FIG. 23A is a plan view covering the case where the concave portion 14 is filled with the gate electrode 24, and the contact plug 28 is formed above the element isolating region 16, as shown in FIG. 15. FIG. 23B is a cross sectional view along the line



23B-23B shown in FIG. 23A.

FIG. 24A is a plan view covering the case where the corner portions 14a, 14b of the concave portion 14 are positively utilized as shown in FIGS. 8 to 10.

5 FIG. 24B is a cross sectional view along the line 24B-24B shown in FIG. 24A.

Further, FIG. 25A is a plan view covering the case where an acute angle portion 14d is formed in the concave portion 14 for promoting the electric field concentration. FIG. 25B is a cross sectional view along the line 25B-25B shown in FIG. 25A.

According to the fourth embodiment, the anti-fuse portion of the present invention can be formed in the minimum processing size of the element region 16a or the gate electrode 24 or in a size several times as large as the minimum processing size noted above, e.g., about  $0.4 \mu\text{m} \times 1 \mu\text{m}$  in the generation of  $0.13 \mu\text{m}$ . Therefore, the area occupied by the anti-fuse portion can be made sufficiently small, compared with the conventional anti-fuse portion, e.g., about  $2 \mu\text{m} \times 10 \mu\text{m}$ . It follows that it is possible to diminish the chip area of the semiconductor device and to decrease the manufacturing cost of the semiconductor device.

25 [Fifth Embodiment]

In general, a capacitor element is formed in many cases within the semiconductor device for stabilizing

the power source. In this embodiment, used is a capacitor formed of a gate insulating film 48, as shown in FIG. 26. For further stabilizing the power source, it is necessary to form a capacitor having a larger capacitance within the semiconductor device. However, in recent years, the area occupied by the capacitor for stabilizing the power source is rendered large relative to the area of the entire chip so as to increase the manufacturing cost of the semiconductor device. Such being the situation, it is required to diminish the area occupied by the capacitor for stabilizing the power source.

In the fifth embodiment, the construction of the semiconductor device having a plurality of concave portions 14 as shown in FIG. 16 is applied to the capacitor element.

As shown in FIG. 27A, a plurality of concave portions 14 are formed within the silicon substrate 11 as in the structure shown in FIG. 16, and each of these concave portions 14 is filled with a gate insulating film 18b' and the polysilicon film 19.

It is desirable to use, for example, a silicon oxynitride film as the gate insulating film 18b' for the capacitor element. The silicon oxynitride film can be formed by, for example, oxidizing the surface of the silicon substrate 11 at 750°C under a nitrogen/water vapor/hydrochloric acid atmosphere, followed by

oxynitriding the resultant oxide film at 900°C under a nitrogen/nitrogen monoxide atmosphere. In the case of using the silicon oxynitride film thus formed, it has been clarified that the breakdown voltage is unlikely to be lowered in the corner portions of the concave portion 14 and in the bottom surface and the side surface of the concave portion 14. Such being the situation, it is possible to use the stepped portion (concave portion 14) of the silicon substrate 11 as a capacitor element for stabilizing the power source, not as the anti-fuse element, as described previously in conjunction with the first to fourth embodiments.

According to the fifth embodiment, the concave portion 14 of the silicon substrate 11 can be used as a capacitor element for stabilizing the power source, not as the anti-fuse element, because a silicon oxynitride film whose breakdown voltage is unlikely to be lowered is used as the gate insulating film 18b'. Also, the surface area of the gate insulating film 18b' can be increased by forming a plurality of concave portion 14 within the silicon substrate 11. It follows that the capacitance of the capacitor can be increased without increasing the area occupied by the capacitor.

For example, where concave portions 14 each having a width of 0.13  $\mu\text{m}$  and a depth of 0.2  $\mu\text{m}$  are repeatedly formed within the silicon substrate 11 with a space of 0.13  $\mu\text{m}$  provided between the adjacent

concave portions 14, it is possible to diminish  
the area of the capacitor element to about 1/2.5 of  
the area in the prior art even in the case of using  
the same gate insulating film. It follows that  
5 the area occupied by the capacitor can be diminished,  
making it possible to manufacture a semiconductor  
device with a low manufacturing cost.

Incidentally, it is desirable for the concave  
portions 14 to be shaped linear as shown in FIG. 27B,  
10 and not to be shaped to form islands as shown in  
FIG. 22A. Where the concave portions 14 are shaped  
linear, the surface area of the gate insulating film  
18b' can be increased so as to increase the capacitance  
of the capacitor without increasing the area occupied  
15 by the capacitor.

Additional advantages and modifications will  
readily occur to those skilled in the art. Therefore,  
the invention in its broader aspects is not limited to  
the specific details and representative embodiments  
20 shown and described herein. Accordingly, various  
modifications may be made without departing from the  
spirit or scope of the general inventive concept as  
defined by the appended claims and their equivalents.